

Performance Study of Adaptive Modulation and Coding Schemes in WiMAX OFDM-based System

Ali H. Al-Qahtani^{#1} and Rabah W. Aldhaheri^{#2}

^{#1}*Department of Electronic Technology, Abha Technical College
Abha, Saudi Arabia*

^{#2}*Department of Electrical and Computer Engineering, King Abdul Aziz University
P.O. Box 80204, Jeddah 21589, Saudi Arabia, Email: raldhaheri@kau.edu.sa*

Abstract— In this paper, we study the performance of an Orthogonal Frequency Division Multiplexing (OFDM) WiMAX transmission system with adaptive modulation and coding (AMC) over different fading channels. An explanation necessary to understand the block diagram of the system is briefly given and a MATLAB code is written to simulate the basic processing involved in this system. The simulation is performed for Fixed and Mobile WiMAX and the performance measures we presented in this paper are: the bit error rate (BER), and the spectral efficiency versus the ratio of bit energy to noise power spectral density (E_b/N_0). The system parameters used in this paper are based on IEEE 802.16 standards.

Keywords -WiMAX, OFDM, IEEE 802.16, AMC

I. INTRODUCTION

The growing demand of all types of services, not only voice and data but also multimedia services, aims for the design of increasingly more intelligent and agile communication systems, capable of providing spectrally efficient and flexible data rate access.

WiMAX, short for 'Worldwide Interoperability for Microwave Access', is a new wireless OFDM-based technology that provides high throughput broadband connection over long distances based on IEEE.802.16 wireless (Metropolitan Area Network) MAN air interface standard [1], [2]. WiMAX supports a variety of modulation and coding schemes to adapt and adjust the transmission parameters based on the link quality, improving the spectrum efficiency of the system, and reaching, in this way, the capacity limits of the underlying wireless channel.

The WiMAX physical layer is based on OFDM. OFDM is the transmission scheme of choice to enable high-speed data, video, and multimedia communications and is used by a variety of commercial broadband systems [3], [4].

Link adaptation techniques, often referred to as adaptive modulation and coding (AMC), are a good way for reaching the cited requirements. It has been shown that adaptive modulation can effectively improve the bit error rate (BER) performance on radio channels, which had suffered from shadowing and multipath fading.

Adaptive modulation enables a WiMAX system to optimize the throughput based on the propagation conditions. Using adaptive modulation scheme, WiMAX system can

choose the highest order modulation provided the channel conditions are good. As the signal-to-noise ratio (SNR) is very good near the base station (BS), so higher order modulation scheme is used in this area to increase the throughput. However, in areas close to the cell boundary, the SNR is normally poor. So, the system steps down to a lower order modulation scheme to maintain the connection quality and link stability. The supported modulations are BPSK, QPSK, 16-QAM and 64-QAM [3].

AMC technique allows the system to overcome time-selective fading. The key element of adaptive modulation is that it enhances the range that a higher modulation scheme can be used over, because the system can bend to the actual fading circumstances, as opposed to having a fixed scheme that is planned for the worst case situations.

In AMC, not only the modulation order but also the forward error correction (FEC) schemes are varied by adjusting their code rate to the variations in the communication channel. An example of utilization of the cited AMC scheme is illustrated in Fig. 1. It shows that as the range increases, the system steps down to a lower modulation, but as closer to the base station, higher order modulations can be used for increased throughput.



Fig. 1 Scheme for the utilization of AMC.

This paper is organized as follows. First, Section I gives an introduction then Section II illustrates the simulated WiMAX system. It gives briefly an explanation of the transmitter, the channel models and the receiver blocks. Section III introduces the results and discussion. Finally, conclusion is presented in Section IV.

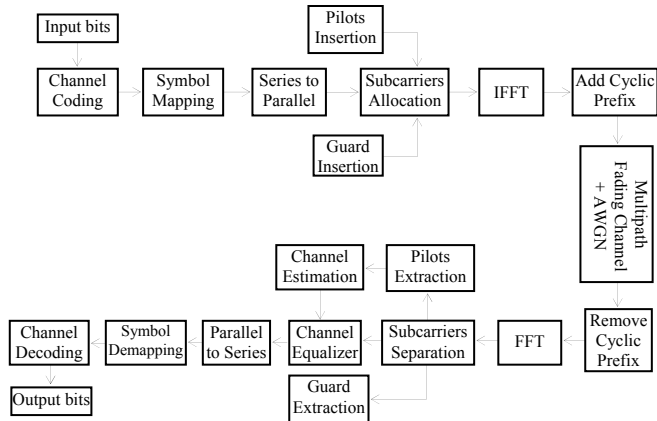


Fig. 2 WiMAX System Block Diagram

II. SYSTEM BLOCK DIAGRAM

A. The Transmitter

Fig. 2 shows the block diagram for the WiMAX simulator used in this paper. At first, random bits are generated, and then, coded by a concatenated Reed-Solomon (RS) and Convolutional encoder. The systematic outer RS code uses a codeword length of 255 bytes, a data length of 239 bytes, and a parity length of 16 bytes. Depending on the currently selected AMC value, the RS code is shortened, to allow for smaller block sizes, and punctured. The outer convolutional code of rate $R = 1/2$ is generated by the polynomials 171_{OCT} and 133_{OCT} . This code belongs to the class of the so-called maximum free distance codes with constraint length equal to seven.

However, after puncturing depending on the AMC value, the maximum free distance is reduced to $d_{\text{free}} = 6$ for $R = 2/3$, $d_{\text{free}} = 5$ for $R = 3/4$, $d_{\text{free}} = 4$ for $R = 5/6$, and $d_{\text{free}} = 10$ for $R = 1/2$, respectively. After coding, an interleaver is implemented to avoid long runs of low reliable bits at the decoder input. The interleaved bits are mapped adaptively to a symbol alphabet [1].

The coding, interleaving, and symbol mapping are the same as defined in the WiMAX IEEE 802.16d specification [1] – [2]. Depending on the feedback information from the receiver, the mapping and the coding rate are adjusted. The seven possibilities for the AMC schemes are summarized in Table I.

After mapping the bits to symbols, serial-to-parallel conversion is carried out to form OFDM symbols. Table II shows the number and type of subcarriers for Fixed and Mobile WiMAX systems. Pilots, a zero DC carrier, and guard carriers are added. Pilots are used at the receiver for channel estimation. After an inverse fast Fourier transformation (IFFT), a cyclic prefix (CP) is added. CP is a copy of the last part of OFDM symbol which is appended to the front of transmitted OFDM symbol. We chose a cyclic prefix length of $1/4$ of the total OFDM symbol length for Fixed WiMAX (and $1/8$ for Mobile WiMAX [2]). CP is used to combat intersymbol interference (ISI) and intercarrier interference (ICI) introduced by the multipath fading channel.

TABLE I
WiMAX MODULATION AND CODING SCHEMES

AMC	Modulation	RS code	CC code rate	Overall Code rate
1	BPSK	(12,12,0)	1/2	1/2
2	QPSK	(32,24,4)	2/3	1/2
3	QPSK	(40,36,2)	5/6	3/4
4	16-QAM	(64,48,4)	2/3	1/2
5	16-QAM	(80,72,4)	5/6	3/4
6	64-QAM	(108,96,6)	3/4	2/3
7	64-QAM	(120,108,6)	5/6	3/4

TABLE II
SUBCARRIERS IN FIXED AND MOBILE WiMAX

Subcarriers type	Fixed WiMAX	Mobile WiMAX
N_{data}	192	360
N_{pilot}	8	60
N_{guard}	56	92
Total subcarriers	256	512

B. Multipath Fading Channel

The channel model used in our simulation for Fixed WiMAX is SUI-3. This model with SUI-x channel models were based on the Stanford University's proposal for broadband wireless access path loss estimation [5]. The parameters of SUI-3 model is depicted in Table III shown below.

TABLE III
SUI-3 CHANNEL MODEL PARAMETERS

	Tap 1	Tap 2	Tap 3
Delay (μs)	0	0.4	0.9
Power (dB)	0	-5	-10
K factor (dB)	1	0	0

For Mobile WiMAX simulation, we chose the COST-231 Hata model. This model is widely used for predicting path loss in mobile wireless system [6]. It was devised as an extension to the Hata-Okumura model. Table IV shows the parameters of the COST-231 model.

TABLE IV
COST-231 CHANNEL MODEL PARAMETERS

	Tap 1	Tap 2	Tap 3
Delay (μs)	0	0.1	0.3
Power (dB)	0	-1.5	-4.5
K factor (dB)	0	0	0

In MATLAB, we used the *ricianchan*(*ts,fd,k,tau,pdb*) function to create a Rice or Rayleigh channel object with an input sample period *ts*, a maximum Doppler shift *fd*, a vector of Rician K-factor (linear scale), a vector of path delays *tau*, and a vector of average path power gains *pdb* (in dB). It then uses the *doppler.rounded* function to create a rounded Doppler object for Fixed WiMAX and the *doppler.jakes* function for Mobile WiMAX [7]. The used channel models have three paths and have the same Doppler spectrum. After creating the channel object in MATLAB, the function *filter* is used and Additive White Gaussian Noise (AWGN) is added to the fading channel.

C. The Receiver

At the receiver, we first perform the inverse operations of the transmitter, that is, cyclic prefix (CP) removal, fast Fourier transformation FFT, extraction of data subcarriers and pilots subcarriers. In order to undo the effects of the multipath fading channel, channel estimation and frequency domain equalization should be done at the receiver. The pilot subcarriers are extracted can then be used for channel estimation at the locations of pilots. To estimate the channel at the data points, interpolation is used. In the simulation least squares (LS) estimate has been used for channel estimation at the pilot subcarriers. If the cyclic prefix is longer than the maximum delay spread of the channel, we can model the effect as a complex multiplication in frequency domain. The equalization thus simplifies to a complex division of the received signal by the estimated channel [8] - [12].

The demapper is implemented as a soft output sphere decoder with a single tree search. The resulting soft bits are passed to a Viterbi decoder and then to a Reed-Solomon decoder. The received bits are compared to the transmitted bits and BER is calculated for different E_b/N_0 . The following table gives the parameters OFDM system used in WiMAX simulation.

TABLE V
OFDM PHYSICAL LAYER PARAMETERS

Parameter	Value	
	Fixed WiMAX	Mobile WiMAX
Channel bandwidth (MHz)	5	5
Sampling frequency F_s (MHz)	5.76	5.76
Sampling period $1/F_s$ (μs)	0.1736	0.1736
Subcarrier frequency spacing $\Delta f = F_s/N_{FFT}$ (kHz)	22.5	11.25
Useful symbol period $T_b = 1/\Delta f$ (μs)	44.444	88.889
G	1/4	1/8
Guard Time $T_g = T_b/G$ (μs)	11.111	11.111
Total OFDM symbol duration $T_s = T_b + T_g$ (μs)	55.555	100

III. SIMULATION RESULTS AND ANALYSIS

A. Fixed WiMAX Simulation Results

We have presented various BER vs. E_b/N_0 plots for some of the mandatory modulation and coding profiles as specified in the IEEE 802.16 standard. The OFDM parameters used in the simulation are given in Table V.

The simulation was performed based on block diagram depicted in Fig. 2. The simulation is carried out for downlink transmissions at a carrier frequency of 2.5 GHz and a 5 MHz channel bandwidth using a single antenna at both the transmitter and the receiver.

Fig. 3 compares the BER curves of the cited modulation for Fixed WiMAX according to Table I. The curves show the BER as a function of the bit energy to noise rate (E_b/N_0), which is a measure of the energy efficiency of a modulation scheme. If a higher E_b/N_0 is needed to transfer data for a given

modulation scheme, it means that more energy is required for each bit transfer. We note that BPSK is more power efficient and need less bandwidth amongst all other modulation techniques used in this OFDM adaptive modulation. In case of bandwidth utilization, the 64-QAM modulation requires higher bandwidth and gives an excellent data rates as compared to others while the QPSK and the 16-QAM techniques are in the middle of these two and need higher bandwidth and less power efficient than BPSK. But they required lesser bandwidth and lower data rates than 64-QAM. BPSK has the lowest BER while the 64-QAM has the highest BER than others.

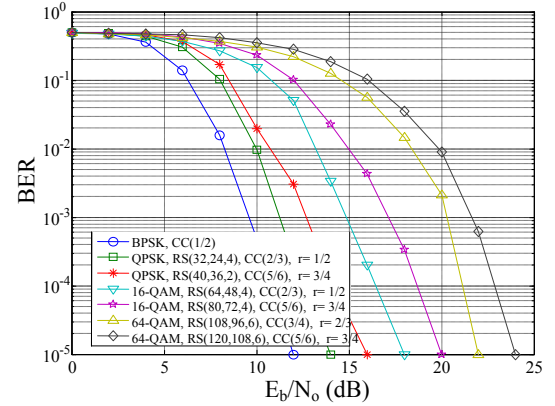


Fig. 3 BER vs. E_b/N_0 for AMC

In general, it can be seen that the lower modulation and coding scheme provides better performance with less E_b/N_0 . This can be easily visualized if we look at their constellation mapping; larger distance between adjacent points can tolerate larger noise (which makes the point shift from the original place) at the cost of coding rate.

The spectral efficiency of a channel is a measure of the number of bits transferred per second for each Hz of bandwidth. Fig. 4 depicts the spectral efficiency as a function of E_b/N_0 corresponding to Fig.3 for various modulation levels.

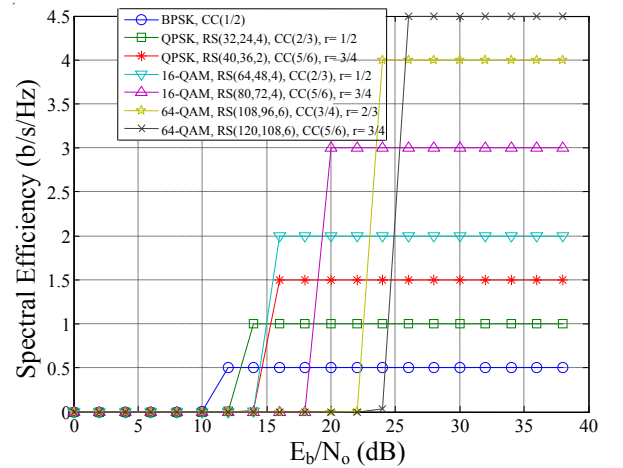


Fig. 4 Spectral efficiency vs. E_b/N_0 for AMC.

B. Mobile WiMAX Simulation Results

When the incoming signal is passed through the channel, the performance of the system degrades due to fading effect and Doppler spread. The channel has three paths and the required signal is corrupted by the previous multipath models in addition to AWGN.

For Mobile WiMAX, Doppler frequency is related to the velocity of the mobile device. We simulated for three different velocities (30, 60 and 100 km/h). We note from Fig. 5 and Fig. 6 that as velocity increases the performance decreases because of increase in Doppler shift in frequency. Doppler shift can be calculated by [3] :

$$f_d = f_c * v/c * \cos(\alpha) \quad (1)$$

where :

f_d : frequency shift (Doppler frequency).

f_c : carrier frequency of the transmitted signal.

v : the receiver speed in m/s.

c : the speed of light (3×10^8 m/s).

α : angle value of arrival wave with horizontal plane.

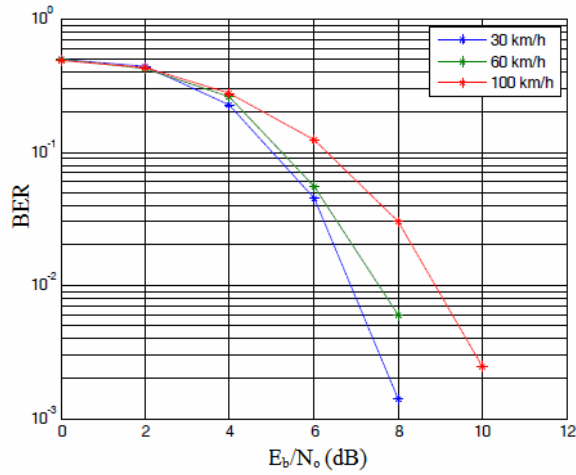


Fig.5 BER vs. E_b/N_0 for different velocities of BPSK, CC(1/2).

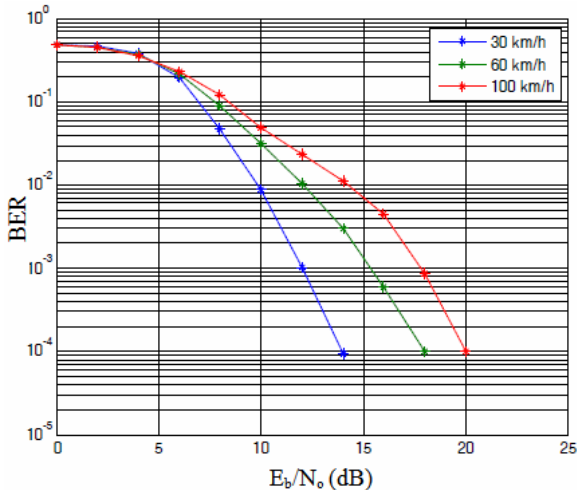


Fig.6 BER vs. E_b/N_0 of QPSK with RS(32,24,4), CC(2/3) for different velocities.

Depending on Equation (1), we can find that the maximum (where $\alpha = 0^\circ$) Doppler shifts in Hz are 69.44, 138.89 and 231.48 for velocities $v = 30, 60$ and 100 in km/h respectively.

IV. CONCLUSION

In this paper, the performance of Fixed and Mobile OFDM-based WiMAX for different modulation and coding schemes are investigated. The simulation results show that we can, depending on the channel conditions, use an optimizing mechanism of AMC that employ multiple modulation and coding schemes in order to instantaneously adapt spectral efficiency to the variations in the channel SNR while maintaining an acceptable BER.

According to this mechanism, as the range increases, the system steps down to a lower modulation, but as closer to the base station, higher order modulations can be used for increased throughput. By setting threshold E_b/N_0 , adaptive modulation schemes can be used to attain highest transmission speed with a target BER.

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